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REPORT EM-51

PRECISION OF THE STANDARD CONCRETE CORE COMPRESSIVE STRENGTH TEST

Engineering
Materials
Office

PRECISION OF THE STANDARD CONCRETE CORE COMPRESSIVE STRENGTH TEST

by

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SUMMARY

A large concrete slab was cast, cured and cored at a job site to determine the precision of the standard concrete core compressive strength test. Twelve laboratories participated in the correlation test; each tested five cores. The cores had an average 28d strength of approximately 38 MPa.

It was found that the within-set (laboratory) and the between-set (laboratory) coefficients of variation were 6.8 percent and 7.3 percent, respectively. The density of the concrete within the slab varied significantly and contributed substantially to the within-set (laboratory) variation.

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INTRODUCTION

In the summer of 1980, a number of 100 mm diameter cores were obtained from a concrete bridge deck for compressive strength testing to evaluate the acceptability of the concrete. Half of the cores were sent to one laboratory and the other half to another laboratory. Both laboratories were to follow the CSA Standard A23.2-14C test procedure and the cores were to be broken at the same time at each of the two laboratories. When the test results from the two laboratories were compared, it was found that they differed by approximately 33 percent of their average in one case and 17 percent in another. A review of the test procedure at each of the two laboratories revealed no departure from the standard.

One laboratory also tested the 28d standard cylinders representing the concrete. It reported the average strength of the cores to be approximately 25 percent lower than the average strength of the standard cylinders.

ACI Standard 318-77 States that "Concrete in an area represented by core tests shall be considered structurally adequate if the average of three cores is equal to at least 85 percent of f'c and if no single core is less than 75 percent of f'c." The test results from one of the laboratories showed that the strength was well below these requirements and from the other laboratory that it complied with the requirements. Faced with this conflicting data and no evidence of testing errors in the two laboratories, it was impossible to decide whether the concrete was acceptable.

Because of the above, a decision was made to carry out an interlaboratory study of the precision of the test method. The study was carried out during April - June 1981 and it is reported herein.

OBJECTIVE

The objective of this study was to determine the precision of the concrete core compressive strength test. Cores were to be obtained from a slab cast at a job site. The method of consolidation of the concrete was to be similar to that of a bridge deck. At least ten laboratories were to participate in the program.

TEST SLAB

The slab was cast on 81 04 29 at Mississauga Road and Hwy. 403, Contract 80-71. The concrete and the slab was as described in Appendix A and Figure A-1 with the exception that the slab was cured with a wet burlap covered with a polyethylene film for 9d. The concrete had a slump of 60 mm and an air content of 5.25 percent.

CORING AND STORAGE OF CORES

The slab was cored at an age of 15d. The coring points were as shown in Figure A-2.All coring was completed the same day. After allowing approximately 15 minutes to surface dry, each core was marked with its identification number and placed in a polyethylene bag. All the cores were stored overnight in a trailer at the job site and the next morning were taken to the Ministry's Downsview laboratory for storage in the bags at normal laboratory air conditions.

SHIPPING OF CORES

Twelve laboratories participated in the study. All with the exception of one were within 80 km distance of the Ministry's Downsview laboratory.

Each laboratory received five cores selected at random. The cores, in their original bags, were shipped to all laboratories the same day (81 05 20) by car with the exception of one set which was sent in a crate by air freight. This set arrived at the laboratory two days later.

TESTING INSTRUCTIONS

Each participating laboratory received the testing schedule (Appendix B) and reporting form (Appendix C).

TEST RESULTS AND DISCUSSION

The strength test results are shown in Table A and the densities in Table B.

Some laboratories measured the diameter of the cores to the nearest 0.1 mm(100.5 -99.0) and the others reported it to be exactly 100 mm. Since most of the laboratories reported the diameter to be 100 mm, all core strengths reported herein were adjusted assuming the diameter to be exactly 100.0 mm. Similarly, all densities were calculated assuming that the relative density of water, in which the cores were weighed, was exactly 1.0.

Laboratory B reported an unsatisfactory break of one of the cores and, for this reason, the test result was rejected.

The test results were evaluated statistically following the procedures described in ASTM C 802-77. The within-set (laboratory) and between-set (laboratory) precisions for the strength test are shown in Table A and for the density test in Table B.

It is evident from Table A that all the laboratory strength averages ($\bar{X}i$) are within two between-set (laboratory) standard deviations from the overall average and that the between-set (laboratory) coefficient of variation is 7.3 percent. It is also evident that most of the variation originates from differences within each set of cores. The within-set (laboratory) variation in this case is caused by the variation in the concrete and in the testing.

Table B shows that the average density ($\bar{X}i$) determined by Laboratory N is almost three between-set (laboratory) standard deviations below the overall average and that all the test results from this laboratory are well below the overall average. The laboratory reviewed its procedure and found that there was an error in the tare. For these reasons their test results were rejected. The rejection reduced substantially the between-set (laboratory) variation. As in the strength test, the within-set (laboratory) component of variance is considerably higher than the between-set component of variance, but each of them is relatively low indicating that the test has good precision.

The analysis of the density - strength relationship (Table C, Figure 1) shows a good overall correlation between the two properties of the cores. Of the twelve laboratories, only test results for laboratory A and L produced a within laboratory correlation coefficient lower than 0.5. All the other laboratories had a within laboratory correlation coefficient of at least 0.630. There was excellent correlation between the averages from the laboratories ($r = 0.924$) and to a somewhat lesser extent between the individual test results ($r = 0.808$).

One 150 mm diameter cylinder (standard casting and curing method) and one core obtained from the slab were tested for their air void system by the linear traverse method in accordance with ASTM C 457-71. The test results were as follows:

	Core	Cylinder
Air content, %	6.8	3.3
Specific surface of the air voids, mm^{-1}	15.0	24.7
Number of voids per mm of traverse	0.255	0.201
Saturated surface dry density, kg/m^3	2345.0	2436

The above differences in air content, density and specific surface of the air voids indicate that the concrete slab contains a large amount of entrapped air. The amount of this entrapped air, as indicated by the density tests (Table B), varied in the slab and this variation contributed significantly to the differences in the densities and strength of the cores.

Table D shows the compressive strength of standard cylinders cured together with the slab and then stored and cured together with the cores. It also shows the strength of the cylinders brought from the job site one day after casting for the laboratory standard curing. It is seen that the overall average strength of the cores was approximately 23 percent lower than the 28d strength of the cylinders regardless of the curing method.

CONCLUSIONS

The following conclusions are based on the study described above:

i) The within-set (laboratory) coefficient of variation of a single compressive strength test result for average strength of approximately 38 MPa (average strength of five cores) is 6.8 percent. Therefore, results of two properly conducted tests by the same laboratory (each consisting of the average of five cores obtained from the same slab made of a single batch of concrete) should not differ by more than 19.2 percent of the average of the two results. This coefficient of variation includes the variation within the concrete and the variation due to testing within the laboratory.

ii) The between-set (laboratory) coefficient of variation of a single compressive strength test result for average strength of approximately 38 MPa (average strength of five cores) is 7.3 percent. Therefore, results of two properly conducted tests in different laboratories (each consisting of the average of five cores from the same slab made of a single batch of concrete) should not differ by more than 20.6 percent. This coefficient of variation includes variation in the concrete, as well as the within and between laboratory variation.

iii) The within-set (laboratory) coefficient of variation of a single density test result (average of five cores) is 0.7 percent. Therefore, results of two properly conducted tests by the same laboratory (each consisting of the average of five cores obtained from the same slab made of the same batch of concrete) should not differ by more than 2.0 percent.

iv) The between-set (laboratory) coefficient of variation of a single density test result (average of five cores) is 0.8 percent. Therefore, results of two properly conducted tests in different laboratories (each consisting of the average of five cores from the same slab made of the same batch of concrete) should not differ by more than 2.3 percent.

v) There is a good correlation between the saturated surface dry density and the strength of the cores. This, together with the excellent precision of the density test, points out that most of the strength variation is due to the variation in the density of the concrete.

vi) The average 28d compressive strength of the cores is approximately 23 percent lower than the average 28d strength of three standard cylinders cured together with the slab and then the cores.

RECOMMENDATIONS

The compressive strength and saturated surface dry density test precisions established by this study should be helpful in the analysis of core test results. However, one must remember that the precisions are for a single batch of concrete and that a greater variation can be expected between cores taken from different areas of a bridge deck. Since there is a good correlation between saturated surface dry density and strength, it is recommended that each core be tested for density before it is tested for strength. This test is simple, inexpensive and may be helpful in the analysis.

ACKNOWLEDGEMENTS

The casting and coring of the field slab was organized by the Construction Office, Central Region. Mr. M. Kalapaca, Assistant Project Supervisor, Contract 80-71, supervised the casting and the coring operations.

Appendix D is an alphabetical list of the laboratories that participated in the study.

TABLE A COMPRESSIVE STRENGTH TEST RESULTS

Laboratory No.	Compressive Strength, MPa	Within Set (Lab)		
		Average $\bar{X}i$	Variance Si^2	Standard Deviation Si
A	38.0 36.9 36.9 39.7 37.4	37.78	1.357	1.16
B	35.1 37.9 43.0 ~~24.4~~ 37.1	38.28	11.309	3.36
C	32.5 40.8 38.6 36.9 35.0	36.76	10.243	3.20
D	36.7 36.9 36.0 38.3 43.3	38.24	8.698	2.95
E	36.7 40.4 37.3 35.3 37.8	37.50	3.505	1.87
F	38.8 37.4 44.0 37.7 37.8	39.14	7.658	2.77
G	38.2 36.3 38.0 41.1 39.1	38.54	3.073	1.75
H	34.0 41.1 36.0 40.2 41.2	38.50	10.860	3.30
K	41.9 39.1 39.6 37.9 45.6	40.82	9.247	3.04
L	34.5 35.4 35.5 36.0 34.3	35.14	0.513	0.72
M	37.1 37.4 36.2 37.4 40.5	37.72	2.657	1.63
N	35.1 35.1 31.1 39.6 38.5	35.88	11.192	3.35

Number of replicates $n = 5$

Number of sets (laboratories) $p = 12$

Overall average $\bar{\bar{X}} = \Sigma \bar{X}i/p = 37.858$

Pooled within-set (lab) variance $S^2 = \Sigma Si^2/p = 6.693$

Variance of set (lab) averages $S_{\bar{x}}^2 = [\Sigma \bar{X}i^2 - p(\bar{\bar{X}}^2)]/p - 1 = 2.207$

Between-set (lab) component of variance $S_L^2 = S_{\bar{x}}^2 - S^2/n = 0.868$

	Components of Variance	Variances	Standard Deviations	Coefficients of Variation
Within-set (lab)	6.693	6.693	2.6	6.8
Between-set (lab)	0.868	7.561	2.8	7.3

TABLE B DENSITY TEST RESULTS

Laboratory No.	Test Results, kg/m^3	Within Set (Lab)		
		Average $\bar{X}i$	Variance Si^2	Standard Deviation Si
A	2371 2362 2334 2359 2354	2356.0	189.5	13.8
B	2361 2347 2373 2355 2352	2358.3	130.2	11.4
C	2327 2361 2347 2347 2331	2342.6	188.8	13.7
D	2336 2343 2328 2342 2396	2349.0	726.0	26.94
E	2355 2365 2355 2341 2344	2352.0	93.0	9.6
F	2371 2341 2385 2334 2378	2361.8	522.7	22.9
G	2368 2345 2341 2373 2347	2354.8	213.2	14.6
H	2340 2382 2341 2355 2380	2359.6	417.3	20.4
K	2351 2346 2359 2366 2407	2365.8	588.7	24.3
L	2329 2326 2329 2328 2323	2327.0	6.5	2.5
M	2336 2353 2338 2354 2366	2349.4	154.8	12.4
N	2150 2186 2169 2223 2203	2186.2	810.7	28.5

Number of replicates $n = 5$

Number of sets (laboratories) $p = 12$

Overall average $\bar{\bar{X}} = \Sigma \bar{X}i/p = 2338.54$

Pooled within-set (lab) variance $S^2 = \Sigma Si^2/p = 336.78$

Variance of set (lab) averages $S\bar{x}^2 = [\Sigma \bar{X}i^2 - p(\bar{\bar{X}}^2)]/p - 1 = 2404.82$

Between-set (lab) component of variance $S_L^2 = S\bar{x}^2 - S^2/n = 2337.46$

	Components of Variance	Variances	Standard Deviations	Coefficients of Variations
Within-set (lab)	336.78	336.78	18.4	0.8
Between-set (lab)	2337.46	2674.24	51.7	2.2

Without Laboratory N

$n = 5$ $p = 11$ $S\bar{x}^2 = 113.52$

$\bar{\bar{X}} = 2352.39$ $S_L^2 = 54.78$

$S^2 = 293.7$

	Components of Variance	Variances	Standard Deviations	Coefficients of Variations
Within-set (lab)	293.70	293.70	17.1	0.7
Between-set (lab)	54.78	348.48	18.7	0.8

TABLE C DENSITY - STRENGTH RELATIONSHIP

Lab. No.	Correlation Coefficient		
	Within Laboratory	Between Laboratory **	All Cores ***
A	0.373		
B	0.630*		
C	0.966		
D	0.983		
E	0.782		
F	0.649	0.924	0.808
G	0.656		
H	0.892		
K	0.755		
L	0.465		
M	0.853		
N	0.765		

* Core with the low strength excluded

** Between average density and strength, Laboratory N excluded

*** Between density and strength of each core; one core from Laboratory B and all cores from Laboratory N excluded

TABLE D COMPRESSIVE STRENGTH, STANDARD CYLINDERS

Age, d	Compressive Strength, MPa	
	Standard Curing	Cured Together With the Slab and Then Cores
7d	41.2 41.2 40.8 Av. 41.1	
28d	49.9 48.0 49.2 Av. 49.0	48.1 49.3 48.7 Av. 48.7
90d	52.5 56.2 Av. 54.4	

Overall average 28d strength of cores $\overline{\overline{X}}$ = 37.9 MPa

Cores to cylinders, 28d strength ratio

Job cured $\frac{37.9}{48.7} = 0.778$

Standard cured $\frac{37.9}{49.0} = 0.773$

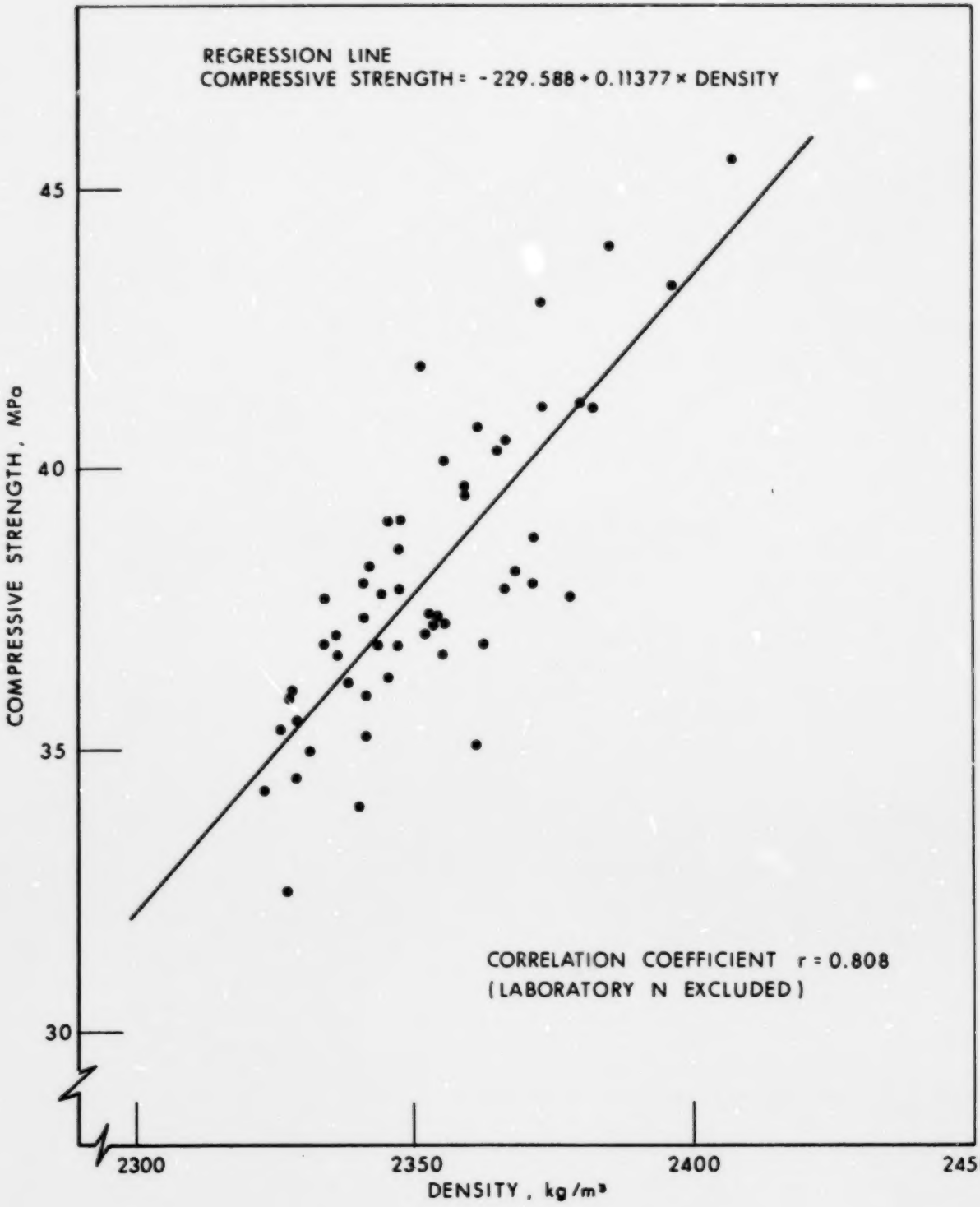

FIG. 1 - RELATIONSHIP BETWEEN STRENGTH AND DENSITY

CONCRETE SLAB FOR MULTI-LABORATORY STUDY OF PRECISION OF CORE STRENGTH TEST

Dimensions of Slab	72" x 112" x 8½" (1800 x 2800 x 212 mm), Fig. A-1
Concrete	35 MPa 6±1.5% air 3±½" (80±10 mm) slump 19 mm max. nominal size aggregate Concrete to be from the middle of truck load.
Test Cylinders	Make 12 standard cylinders - 3 to be cured together with the slab and delivered to Downsview Concrete Laboratory with the cores and 9 to be delivered to Downsview Concrete Laboratory the next day after casting the slab for 7d, 28d and 90d tests.
Consolidation of Concrete	Internal Vibrator (as in bridge deck)
Finishing	Wood screed (sawing motion)
Curing	Wet burlap for 3d
Coring	16-20 days after casting; 4" (100 mm) diameter, 8½" (212 mm) long cores; deliver cores to Concrete Section, Downsview immediately after coring.
Core identification	As shown in Figure A-2 A-1, A-2 ... A-6 B-1, B-2 ... B-6 --- J-1, J-2 ... J-6

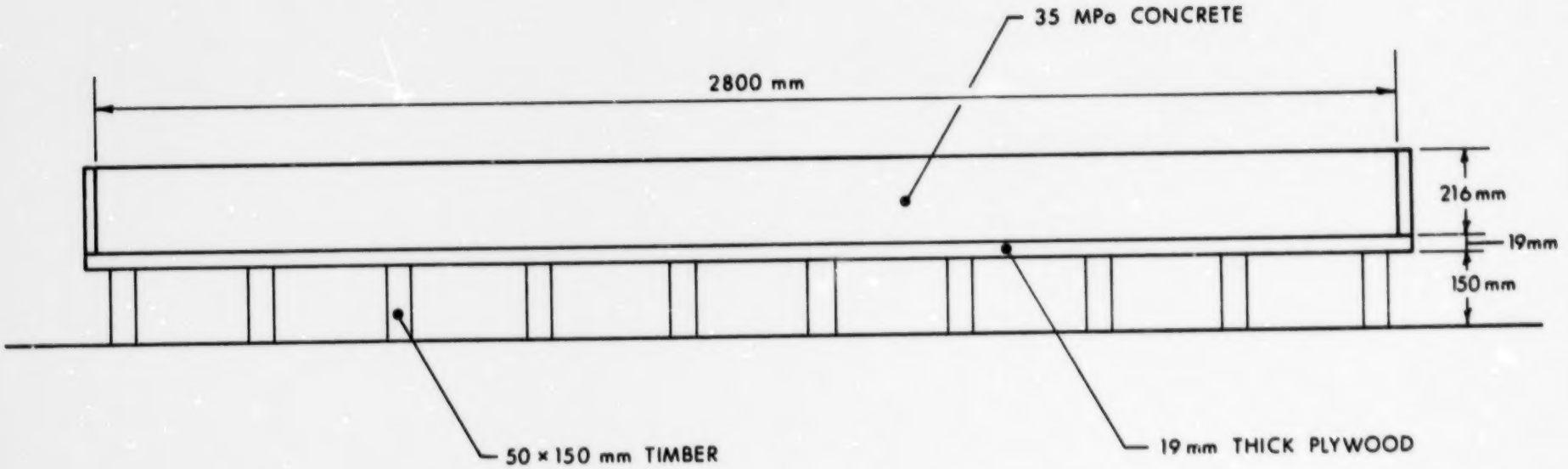

FIG. A-1 - CONCRETE TEST SLABS

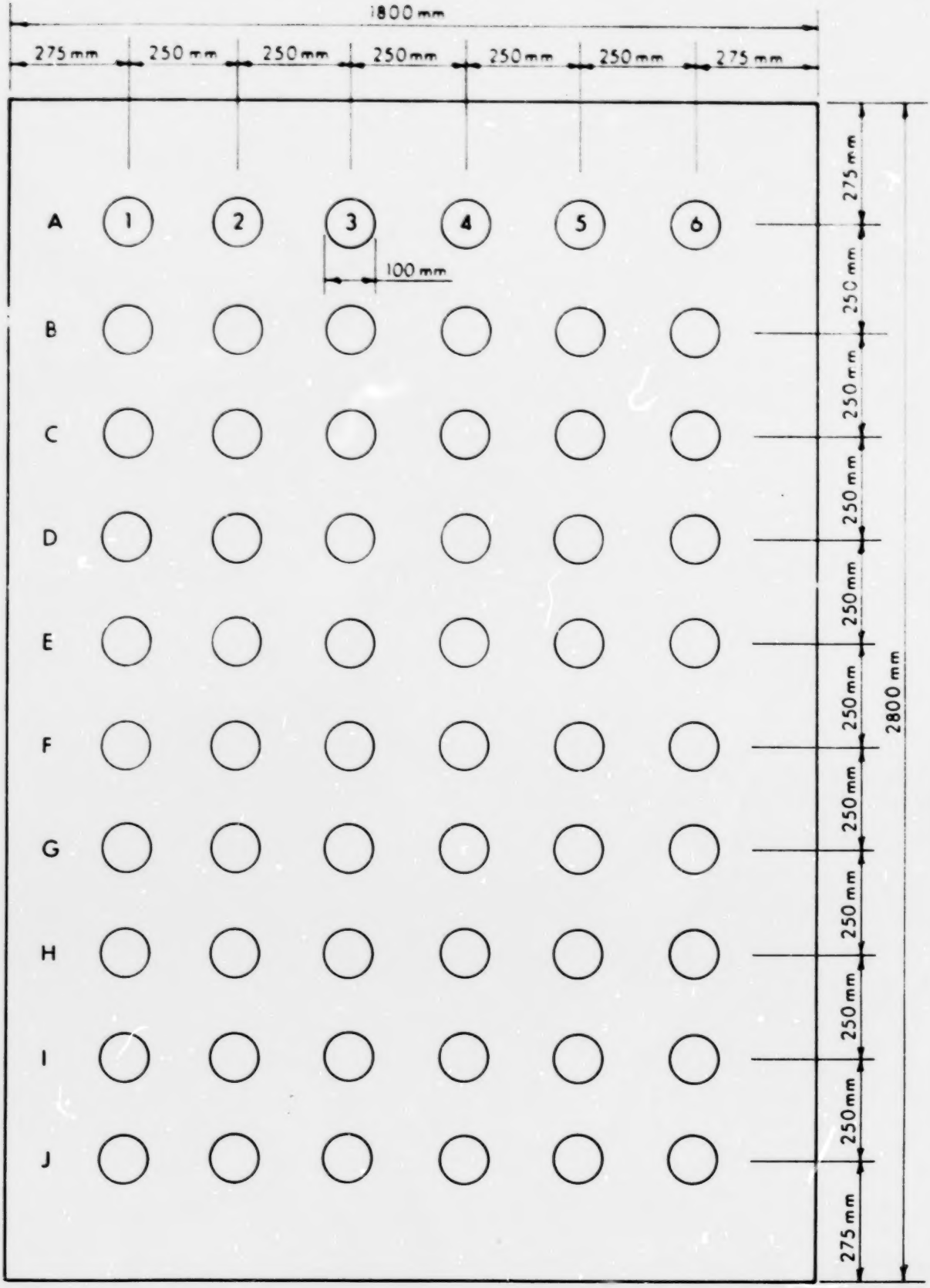

FIG. A-2 - LAYOUT OF CORING POINTS

CORE TEST PROCEDURE
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1) Follow CSA Standard CAN3-A23.2-14C procedure

2) On arrival, place the cores as received (in polyethylene bags) at normal laboratory conditions. The following day (May 21st) remove the cores from the bags and saw so that the length of the core is 7 3/4 inches. The top cut shall be approximately 1/2 inch from the top of the core. After sawing store the cores at normal laboratory conditions until May 25th.

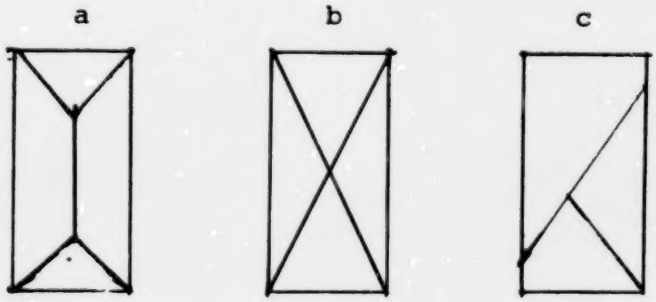
3) On May 25th immerse the cores in water for 44±4h.

4) On May 27th, remove the cores from the water storage and determine density of each core by weighing in water and air (dry with an absorbent cloth). The weights shall be determined to the nearest 1 g.

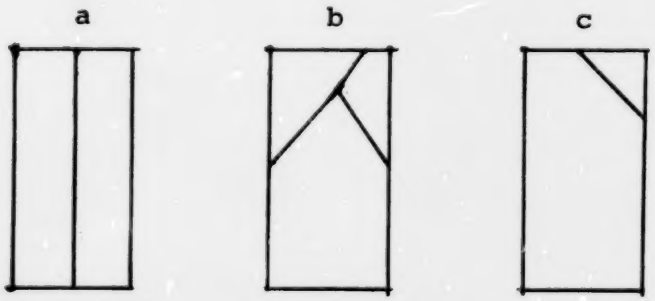
5) Cap each core with a sulphur mortar and break two hours later in compression. Examine for form of break and type of fracture. Retain all broken cores for four weeks.

Form of Break

1. Satisfactory



2. Unsatisfactory



CONCRETE CORE CORRELATION
TEST REPORT

Laboratory No. _____ Date Received _____ Date Tested _____ Tested by _____

Core No.	Mass in H_2O	Mass in Air	Density kg/m^3	Diameter mm			Length mm	Maximum Test Load N	Compressive Strength MPa	Break Form	Type of Failure	
				1	2	Avg.					Bond A	Agg. A

Remarks

Immediately after completion of the tests, mail report to: Mr. John Ryell
Ministry of Transportation and Communications
Concrete Section, Room 111, Central Building
1201 Wilson Avenue, Downsview, Ontario M3M 1J8

PARTICIPATING LABORATORIES

Project EM-69

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Ontario Hydro
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